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RESEARCH MEMORANDUM

An Annotated Bibliography on the Troubleshooting of Electronic Equipment

by

Clinton S. Trafton

Approved:

Robert G. Smith, Jr.

ROBERT G. SMITH, JR.
Director of Research

U. S. Army Air Defense
Human Research Unit
Fort Bliss, Texas

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Task MAINTRAIN

INTRODUCTION

The purpose of Task MAINTRAIN is to develop techniques for improving the training and proficiency of electronics maintenance technicians. Since trouble shooting, i.e., locating malfunctioning parts, is one of the most difficult tasks involved in maintenance, recent efforts have been devoted largely to this aspect of maintenance.

A necessary step in the conduct of trouble shooting research was to review the relevant literature. The present bibliography was prepared as part of the review process, and was intended primarily for use by MAINTRAIN staff members. It is published in the hope that it will be of value to other persons interested in trouble shooting or trouble shooting research.

In preparing the bibliography, no attempt was made to include articles published after May, 1961, or those referenced in A Review of Troubleshooting Research, 1956, by Standlee, Popham, and Fatter (see page 17).

References and annotations 44 through 74 are quoted from Maintenance Personnel and Training Research: A Bibliography, 1958, by Stiles and Demaree (see page 17). They are included here for ease of reference.

Although an effort was made to include all pertinent references, some omissions have undoubtedly occurred. Suggestions for corrections or additional references will be welcome.

KEY TO ABBREVIATIONS OF ORGANIZATIONS

AFPTRC	Air Force Personnel and Training Research Center, Air Research and Development Command, Lackland Air Force Base, Texas.
AIR	American Institute for Research, 410 Amberson Avenue, Pittsburgh 32, Pennsylvania.
ASPRL	Armament Systems Personnel Research Laboratory, Air Force Personnel and Training Research Center, Lowry Air Force Base, Colorado. (Later renamed Maintenance Laboratory).
HRRC	Human Resources Research Center, Air Research and Development Command, Lackland Air Force Base, Texas. (Later renamed Air Force Personnel and Training Research Center.)
HumRRO	Human Resources Research Office, The George Washington University, Post Office Box 3596, Washington 7, D. C.
ML	Maintenance Laboratory, Air Force Personnel and Training Research Center, Lowry Air Force Base, Colorado.
ONR	Office of Naval Research, Department of the Navy, Washington 25, D. C.
PRFASD	U. S. Naval Personnel Research Field Activity, San Diego, California
TARL	Training Aids Research Laboratory, Air Force Personnel and Training Research Center, Chanute Air Force Base, Illinois. (Later merged with the Maintenance Laboratory.)
USC	Department of Psychology, University of Southern California, Los Angeles, California.
WADC	Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio.

1. ALTMAN, J. W. Design of procedures for systematic troubleshooting. In second Symposium on Electronics Maintenance, Office of the Assistant Secretary of Defense, Research and Development. Report No. PPT 202/5. May, 1956.

The paper discusses three major phases in systematic troubleshooting:

(1) Routine checks to identify malfunction symptoms.
(2) Analysis of symptom patterns in order to narrow the area of malfunction, using routine check results.
(3) Special checks to isolate the malfunction to replaceable or repairable components.

The author feels that the system designer can best supply instructions, diagrams, and efficient checking sequences to aid the technicians trouble shooting task.

2. AUKES, L. E. and SMITH, P. N. Report of TA & D and TARL Conference, 5-7 May, 1954. AFPTRC-TARL Technical Memorandum, AFPTRC-TARL-TM-54-1, pp. 43-50, Aug. 1954.

The report summarizes the proceedings of the joint conference of TA & D and AFPTRC personnel on May 5-6-7, 1954. The report contains three articles concerning research and development of troubleshooting which are summarized below:

A. HOEHN, A. J. Improving troubleshooting through a pre-planning technique.

A study conducted in the generator phase of an electrical course at Chanute AFB to determine if a specific pre-planning procedure will improve accuracy and speed of troubleshooting. Performance of a group of students given typical instructions to think through the possible causes of malfunction before acting was compared to that of a group given similar instructions. In addition, the second (experimental) group was required to indicate on a form the checks they would make and the order in which they would make them. The results indicated that a larger percentage of students in the experimental group than in the control group located the malfunction. It is pointed out that merely telling the student to pre-plan his troubleshooting is not enough to produce improved performance. A specific procedure for pre-planning and practice in using the procedure is required.

B. SMITH, P. N. Field evaluation of a troubleshooting aid.

Two groups of Q-24 radar mechanics were asked to locate eight malfunctions in the Q-24 bomb release chain. One group (experiment) used a set of directions which indicated the checks and the sequence of checks which should be made in order to locate malfunctions in the Q-24 bomb release chain, while the control group used normal procedures and materials. The experimental group reported that they would have removed an average of seven components to locate the eight faults while the control group reported that they would have removed an average of thirty-two components.

C. JUDY, C. J. The development of a troubleshooting aid for the electronic fuel control system on the F-86D Airplane.

A paper which discusses arrangement and content in the development of a graphic troubleshooting aid for use with the F-86D aircraft electronic fuel control system.

3. BRIGGS, L. S. and DU VALL, W. E. Design of two fire control system maintenance training devices. ML Technical Report 57-7, Sept. 1957.

Two training devices are described which appear to have achieved improvements over earlier types. The trainers developed were: (a) a radar procedural trainer, and (b) a computer checking, adjusting, and troubleshooting device. The development of these trainers is outlined. Also included are job task descriptions for the maintenance of the MG-10 Fire Control System (Aircraft and Weapon Control System).

4. BRYAN, G. L. and SCHUSTER, D. H. An experimental comparison of troubleshooting training techniques. Nonr-228(02), Project NR153-093, Department of Psychology, Univ. of Southern California, Dec. 1959.

The present study was designed to study the effects of various training techniques upon subsequent testing of troubleshooting skill. Students of the U. S. Navy Electronics School at Treasure Island served as subjects. The variables studied were three forms of guidance during troubleshooting and two conditions of explanation following steps in the troubleshooting sequence. The three conditions of guidance were:

(a) No guidance. Students not restricted in manner of checkout of the system.
(b) Partial guidance Student decided upon next step but required to ask permission to make the circuit check. Only those checks which conformed to predetermined sequence of check were allowed.
(c) Complete guidance. Subject followed an itemized prescribed checking sequence.

The explanation conditions were:

(a) No explanation.
(b) Explanation. Following completion of a step in the checking sequence, subjects were given a written sheet which pointed out the rationale of the checking sequence and pointed out how the results should be interpreted.

Two criterion tests, one given immediately following training, and the other after three weeks, indicated that guidance training and explanations were effective in producing improved trainee troubleshooting behavior.

5. CHALMERS, E. L., Jr., MORRISON, E. J., BRIGGS, L. J., And PENS, E. H. Evaluation of a method for teaching troubleshooting techniques. ML, AFPTRC Technical Memorandum ML-TM-57-34, December 1957.

A study was conducted in order to evaluate the usefulness of the E-4 Fire Control System Troubleshooting Trainer in teaching effective troubleshooting techniques. The subjects were E-4 Fire Control System mechanics with at least six months of field experience. These subjects were trained and tested in troubleshooting of the E-4 Fire Control System. Significant improvement in knowledge of the E-4 Fire Control System and the troubleshooting techniques employed by the mechanics was found. Recommendations for future use of the Troubleshooting Trainer are made.

6. CZEH, R. S. Studies of complex behavior and their relation to troubleshooting in electronic equipment. HumRRO Staff Memorandum, Training Methods Division, Task TRACE, June 1957.

"The relationship between research findings concerned with performance in complex situations and troubleshooting in electronic equipment has been discussed. It has been concluded that the study of human problem solving, concept formation, probability learning and so forth, has provided little data of immediate use to the researcher in electronic troubleshooting, but has provided certain hints as to important variables which must not be ignored. Various proposed methods of troubleshooting have been noted, and a study dealing with troubleshooting process and training methods to teach the process has been outlined. The study treats troubleshooting as a generalizable skill which may be studied in the laboratory ..."

Also included is a plan for developing troubleshooting procedures in the laboratory and for teaching these procedures.

7. DALE, H. C. A. A field study of fault-finding in wireless equipment. APU 329/58, March 1958, Applied Psychology Research Unit, MRC, Cambridge, England.

A study was conducted to determine the nature of troubleshooting behavior, whether or not differences in individual methods of troubleshooting are related to differences in practical experience and familiarity with the equipment, and the characteristics of efficient troubleshooting.

Fifteen subjects (experienced with the equipment) were observed while troubleshooting equipment in an attempt to locate an inserted malfunction. As a result of these observations and subject interviews, a strategy of troubleshooting was developed.

8. DALE, H. C. A. Fault finding in electronic equipment. Ergonomics, 1958, 1, 356-385.

"...The use of laboratory tasks, in which the secondary difficulties associated with the real job through poor Human Engineering, and a lack of suitable data books and diagrams are eliminated, shows that most men do not search efficiently. Their behaviour is influenced to a considerable extent by irrelevant factors; it changes if tasks are presented in different ways; and in a given task irrelevant features of the display affect their procedure.

"The appropriateness of a man's strategy appears to be positively correlated with his intelligence. This suggests that if the intelligence level of men recruited for fault-finding training is reduced, then not only will they experience more difficulty in assimilating electronic theory but when they come to the actual job they will use less effective strategies in their fault finding. The problem of training them to use better strategies is discussed.

"Experiments by the author are described and set in relation to previous work."

9. DALE, H. C. A. On the nature of fault finding in electronic equipment. APU 328/58, March 1958, Applied Psychology Research Unit, MRC, Cambridge, England.

A theoretical discussion of some psychological problems related to troubleshooting. Methods of equipment testing and efforts and time considerations for each method are discussed.

10. FOLLEY, J. D., Jr. and ALTMAN, J. W. Human factors in maintenance. Part IV. Factors influencing the maintenance of electronic equipment. USN Training Device Center, Port Washington, N. Y. Technical Report NAVTRADEVCEN 20-05-23-4, Sept. 1958.

The problem of maintaining complex equipment is investigated in a nine-part program. Part IV (reported here) delineates many of the general features and cautions necessary for effective

maintenance such as personnel capabilities and limitations, designing for maintainability, and maintenance procedures. Included in the section covering maintenance procedures is a discussion of troubleshooting procedures. Included are discussions of routine checks, symptom-pattern analysis, and special checks.

11. GLANZER, M. Diagnostic (troubleshooting) skills and their evaluation. Occupational Psychology, October 1958, Volume 32.

The area of troubleshooting is discussed. General procedures of malfunction location such as tests built into equipment, replacement of suspected parts, and systematic checks are pointed out with a break-down of the steps involved in systematic systems checks. Troubleshooting approaches such as the cookbook method, the probabilistic or failure rate method, and the signal flow tracing method are examined. Also discussed are some techniques developed to solve troubleshooting problems.

12. GLANZER, M and GLASER, R. A study of non-intellectual correlates of troubleshooting ability: Rigidity measures. WADC Technical Report, TR 58-488, October 1958.

The main objective of this study was to determine the relationship between measures of problem solving rigidity and performance on both novel and routine troubleshooting tasks concerned with electronics equipment. A battery of 13 rigidity tests was constructed in terms of four categories: ability to change performance sets; ability to change perceptual sets; preference for highly structured, simple stimuli; and general attitudes. Alternate sets of criterion problems each included three routine and three novel troubleshooting problems. The hypothesis to be tested was that scores on the tests of the rigidity battery would be significantly related to performance on the novel problems, but not on the routine problems. Results from administration to airmen trainees showed some low relationships between the rigidity measure and both the novel and routine criterion measures. No differential pattern of relationships appeared between the rigidity tests and novel troubleshooting performance as compared with performance on routine problems. Combinations of the Electronics Aptitude Index with selected rigidity test scores showed only slightly improved prediction over the aptitude score alone, of training school performance.

13. GLUSS, B. An optimum policy for detecting a fault in a complex system, Operation Research, July-August, 1959, 7 (4), 468-477.

Two models are developed and presented in equation form which lead to an optimum policy for troubleshooting of complex

electronic systems. The troubleshooting policy minimizes the amount of time required for malfunction location. One model assumes that overall tests of each module may be performed in addition to within module component checks. The other model assumes that overall module checks are not possible. An example is presented for the latter model.

14. GOLDBECK, R. A., KAY, E., WILLIAMS, W. L., Jr. and ROGERS, J. P. A survey of organizational maintenance of the NIKE AJAX Missile, HumRRO Research Memorandum, Subtask MAINTRAIN III, July 1960.

    A survey was conducted to provide information regarding missile maintenance which would be helpful in the evaluation and modification of NIKE AJAX maintenance personnel training, the allocation of maintenance personnel, and the development of effective maintenance procedures and training. Three major types of maintenance activities were identified and data collected concerning each: (1) Missile Assembly and Servicing, (2) Preventive Maintenance and (3) Trouble Analysis and Repair. The nature and frequency of the on-site trouble diagnosis and repair activities were determined. Alternative ways of meeting maintenance requirements are presented.

15. HANSEN, O. K., FRANKS, P. E., and MODRICK, J. A. Nature and use of the MAC-2 (Malfunction and circuitry) Trainer. WADC Technical Note TN 59-140, May 1959.

    The MAC-2 Trainer, simulating the data flow of the MA-7A bomb-nav system, can be used for training and proficiency measurement in the use of data flow information and technical manuals by flight line mechanics. The report includes a brief history, physical and functional characteristics, purpose, advantages and limitations, suggested modifications, research problems and empirical basis for uses of the trainer. The trainer has considerable face validity but its specific purpose and the limited knowledge about its proper use should be considered in recommending this type of training equipment.

16. HITCHCOCK, L., Jr., MAGER, R. F., and WHIPPLE, J. E. Development and evaluation of an experimental program of instruction for fire control technicians. HumRRO Technical Report 46, May 1958.

    Following previous analysis of troubleshooting behaviors and maintenance habits of both experienced and inexperienced technicians, an experimental course of instruction for M33 Fire Control System Maintenance was developed. Two groups of technicians received training using the experimental course of instruction, and were subsequently tested on the M33 Mechanic Proficiency Test. As a result, certain recommendations for curriculum change of the U. S. Army Air Defense School on M33 Maintenance are made.

17. HOEHN, A. J. The development of training programs for first enlistment personnel in electronics maintenance MOS's. HumRRO, Research Memorandum, Task JOBTRAIN II, 1960.

A series of guidance documents is presented concerning the design and development of integrated school and on-the-job training programs for first term enlisted personnel in electronics maintenance positions. Each document in the series deals with a general decision area such as:

1. Defining objectives of training in terms of required performance capabilities.
2. Deriving training content from performance requirements.
3. Designing handbook (job-aid) materials.
4. Planning the school training activities and designing the associated training materials.
5. Testing individual trainees and assessing the training program.

18. HOEHN, A. J., and LUMSDAINE, A. A. Design and use of job aids for communicating technical information. AFPTRC Technical Report -- TR-58-7, January 1958.

Preliminary studies were made of methods for determining efficient standard courses of action in troubleshooting. These were designed to provide a basis for specifying content of procedural instruction for isolating malfunctions. It was concluded that step-by-step instructions have been constructed which minimize requirements for advanced training for troubleshooting of complex equipment. Other conclusions concerning job-aids, content of troubleshooting routines, analyzing job-tasks, and recommendations for further research are presented.

19. JOHNSON, S. M. Optimal sequential testing. The Rand Corporation, Santa Monica, California, Research Memorandum RM-1652, March 1956.

The problem of troubleshooting electronic gear is approached from a mathematical standpoint. Assuming that the cost of each step in locating a malfunction and the probability of a component failure are known, an optimal sequence of component testing is presented. The method of malfunction location can be used to locate faulty components or parts of components.

20. KRIEGH, B. and WAGNER, S. F. Improved checking sequences for troubleshooting. ML, Technical Memorandum ML-TM-58-1, January 1958.

This report is an extension of the results of the report "Optimal Sequences for Troubleshooting", (Technical Memorandum ML-TM-57-30, December 1957) in which a computational procedure

was devised for determing the least average time required to check a chain of component elements in series in order to locate a defective component. The present study extends those results to: (a) the problem of several chains of elements in parallel, (b) the problem of mixed checks for a single chain of elements, and (c) a comparison procedure that will permit the best checking sequence to be obtained by longhand computation.

21. LARKINS, J. T., and JEWELL, D. S. On-the-job training and proficiency of K-system mechanics. AFPTRC Technical Report TR-58-5, January 1958.

"A final report on Task 37301, Principles of Effective OJT for Armament Maintenance. Research and development studies conducted in the maintenance personnel and training field are described, specifically in the areas of proficiency and performance evaluation of flight-line maintenance personnel for bombing-navigational systems and methods for the improvement of on-the-job training for these personnel. Tests, paper-and-pencil trainers, trainers, and job aids experimentally developed and evaluated under this task are briefly described. These include: K-System MAC-1 Trainer, MAC-2 Trainer, GETS Trainer. The Trainer-Tester, Malfunction-Information Trainer, and Trouble Locator".

22. MILLER, R. B. and SLEBODNICK, E. B. Research for experimental investigations of transferable skills in electronic maintenance. AFPTRC Technical Report TR-58-2, January 1958.

Two laboratory experiments were conducted to determine the degree of improvement in maintenance skills resulting from training in generalized troubleshooting procedures as compared to specific training on prescribed maintenance tasks. In the first experiment, subjects performed electronic maintenance tasks, (1) after learning "what to search for" in the job environment, or (2) following study of "principles of troubleshooting". In the second, subjects were tested on performance of specific troubleshooting problems after training on (1) troubleshooting principles, or (2) concepts of data flow. It is recommended that troubleshooting be taught in the form of a general strategy based on principles for making efficient fault location. Concepts of data flow should precede training of troubleshooting principles, so that the student can trace linkages from input to output of systems and subsystems.

23. MONTAGUE, W. E., and KOLSTOE, R. H. Ordnance NIKE detachment electronics maintenance personnel: Analysis of activities with implications for training, HumRRO Staff Memorandum, Task NICORD, May 1957.

Maintenance personnel in Ordnance NIKE Detachments were observed and data obtained concerning their dtuies and qualifications.

The data were collected using questionnaires, interviews, rating scales, card-sorting tasks, repair record forms and observations of field activities. The repair personnel were found to be above the Army average in terms of mental aptitude and education. Data concerning kinds of malfunctions usually encountered, parts replaced most often, time to isolate and correct malfunctions, and common sources of malfunction were collected. Information was also obtained concerning the adequacy of training courses.

24. RIGNEY, J. W., SCHUSTER, D. H., BUDNOFF, I. J. and RUNYAN, T. L. Field evaluation of a troubleshooting training package. Department of Psychology, University of Southern California, Technical Report No. 32, April 1961.

Two studies were conducted to evaluate a training package, consisting of refresher lectures, troubleshooting principles and problems in a programmed-learning format, and criterion problems.

In the first study, conducted at San Diego, with technicians from the pacific fleet, the subjects were classified as "experienced"or "inexperienced" in terms of their experience with loran or radar gear. Following a week of training, both groups made significant gains in performance on criterion problems. The experienced group improved significantly on all three behavioral measures of troubleshooting ability while the inexperienced group improved on only two. There were significant differences in the experienced and inexperienced group's performance.

In a second field test, conducted in a Class "A" Electronic Technicians School, an experimental group solved more radar criterion problems after training than a conventionally trained group, but the behavioral measures of troubleshooting were not significantly different.

25. RULON, P. J., SCHWEIKER, R. F. and GILBERT, A. C. F. Electronics maintenance training: Experimental tryout of diagnostigrams and backtracks. ML Research Report AFPTRC-ML-ERC, AF18(600)-1355, Rep. 1-58, January 1958.

The present study was conducted in order to search for methods of simplifying the training of troubleshooting personnel and/or the troubleshooting task. Twenty-eight high school students, with little or no technical training were divided into two groups. One group was given troubleshooting training using the Diagnostigram and the Backtrack method. The second group was given troubleshooting training in a manner as similar as possible to existing maintenance training courses. Following training a

three-part test was administered; part one consisted of a performance test of [illegible] malfunctions; part two a written test dealing with the operating characteristics of a computer; part three a written test on electronics in general, computer theory, and the theory of computer operation. The results were as follows: The Backtrack-Diagnostigram (experimental) group successfully isolated more malfunctions in the trouble-shooting performance test. The training course group (control) obtained higher scores on the basic information and theory test.

26. SCHUSTER, D. H. Principles of logical troubleshooting: Electronics Personnel Research Group, USC. Project NR 153-093, Contract Nonr-228(02), 1960.

This book is designed as a training aid to enable a trouble-shooter to logically analyze the troubleshooting information he obtains from the malfunctioning system. The book attempts to teach the reader the general principles of troubleshooting while assuming that the details of a particular system and use of test equipment is already known. The material in the book is presented in a scrambled manner with a question and several multiple-choice answer possibilities presented on each page. Incorrect answer choices are explained and the student is asked to continue selecting until the correct answer is chosen.

27. SHRIVER, E. L. Determining training requirements for electronics system maintenance: Development and test of a new method of skill and knowledge analysis. HumRRO Technical Report 63, Task FORECAST I, June 1960.

"New methods of task and skill analysis were developed and used to establish the content of a training program for the operation and maintenance of the M33 Anti-aircraft Fire Control system. A 12-week experimental training program was administered to a group of students who were matched in background with a group of students from the standard 30-week M33 repairman course sequence...The students of the experimental and standard courses scored equally well on the postgraduation performance test (on ability to energize, adjust, and troubleshoot to individual parts of the M33 radar system). In view of the fact that the experimental group had only 12 weeks of training, as compared with the standard group's 30 weeks, it is concluded that considerable training time can be saved with no loss in performance skill, using a training course based on the methods developed in this research."

28. SHRIVER, E. L., FINK, D. C., TREXLER, R. C. Increasing electronics maintenance proficiency through cue-response analysis. HumRRO Research

Memorandum, Risk FORECAST II, October 1959.

Two studies were designed to test the potential for increasing electronics maintenance proficiency through the use of job analysis methods as developed in Cue-Response Methods of Analyzing Electronic Systems, Edgar L. Shriver, Human Resources Research Office, Washington. The first study established a student proficiency level in repairing the Track subsystem of the M33 radar. The second study was designed to determine the effectiveness of a low cost mock-up of the M33 Track subsystem when substituted for the actual equipment in some practical exercises. The exercises taught operational skills, recognition skills, interpretational skills and troubleshooting logic. Students using the mock-up demonstrated an ability to repair 20 per cent more of the malfunctions presented in the proficiency test than had students in any previous study. This represented a statistically significant increase in electronic maintenance effectiveness.

29. RHEEM MANUFACTURING CO. A lesson on troubleshooting strategy. Electronics Division, Training Aids Dept., 7777 Industry Ave., Rivera, Calif., 1958.

A lesson in troubleshooting simple series circuits is presented using the "scrambled" book method. A discussion of the advantages of the "scrambled book" is included.

30. WARREN, N. D., DOSSETT, W. F. and FORD, J. S. A correlation analysis of achievement in a generalized electronic troubleshooting course. ML, Technical Note 57-148, December 1957.

Sixteen standardized tests of special abilities were given to 90 male subjects and a factor analysis conducted to reveal underlying factors in troubleshooting ability. Used as a measure of the achievement of troubleshooting ability were written tests and Generalized Electronic Troubleshooting Trainer (GETS) scores following training on the GETS trainer. Attention was also given to the prediction of achievement scores from the 16 ability tests.

31. WARREN, N. D., DOSSETT, W. F., and FORD, J. S. An experimental analysis of achievement in a generalized electronic troubleshooting course. AFPTRC Research Report TN-57-147, December 1957.

"This report summarizes an experimental study of the effects of (a) three levels of generalized training-practice on troubleshooting problems and (b) three levels of general ability (California Test of Mental Maturity) on troubleshooting achievement. Sixteen standardized tests of special abilities were also given. Achievement was measured by scores on a written test designed to measure conceptual understanding of troubleshooting,

and on performance on problems presented in the Generalized Electronic Troubleshooting (GETS) Trainer. Three performance scores were used: number of actions taken, time taken, and a composite score. Subjects were 90 high-school males, 16-19 years old, with mental ages from 156 to 253 months. Apparent relationships of mental age and training level with troubleshooting achievement varied according to the achievement score used. All the achievement scores were more significantly related to specific mental abilities--especially evaluative reasoning--than to general ability, as measured. Effects of increased practice seemed limited to the more difficult problems. In general, the generalized troubleshooting training increased efficiency in utilizing sympton information."

32. WARREN, N. D., SCHUSTER, D. H., FRENCH, R. S., LATINA, R. J. and NELSON, R. A. Development and evaluation of a troubleshooting aid for flightline maintenance of a complex electronic system. AFPTRC Development Report TN-58-1, January 1958.

"In this study, the feasibility of a troubleshooting aid for the K Bombing-Navigational System was investigated... On the basis of the evaluation made, a troubleshooting aid for inexperienced mechanics working with complex systems appears to be practical as well as possible. Specifically, a trouble locating handbook was developed, evaluated and found to be potentially valuable for operational use...The evidence suggests that the K-System Trouble Locator developed in this study compensates for the lack of broad training and experience for mechanics just out of school as well as being valuable to experienced personnel."

33. WEISS, E. C., and WULFF, J. J. Design and evaluation of a self-tutoring method for on-site training in SAGE AN/FST-2 troubleshooting. II. A revised program. Psychological Research Associates, PRA Report 61-1, Arlington 2, Virginia. (AFCCDD-TN-60-61).

"A previous study, reported in AFCCDD-TN-60-26, (reported above) developed and field tested a programmed course of instruction to foster maintenance performance by AN/FST-2 maintenance technicians. The present report describes a work effort which was initiated to translate the prototype training materials developed during the previous study into a storyboard format from which a sound film could be produced. However, because the results of the field test indicated certain deficiencies in the previous program the storyboard materials are more than a translation of the previous text into a format which meets the requirements for the production of a film. Rather, they represent a complete revision of the prototype course in terms of the troubleshooting procedures and materials, the course program, and the more aspects of the training materials such as the test procedures which are employed. The most significant aspect of

the revision is the elimination of the more generalized aspects of troubleshooting, per se, and a heavier emphasis from the outset on their application to the AN/FST-2. A diagram of the new program is also presented."

34. WEISS, E. C., WULFF, J. J., McLAUGHLIN, J. T., WALKER, W. T., and CARTER, R. F. Design and evaluation of a self-tutoring method for on-site training in SAGE AN/FST-2 troubleshooting. Psychological Research Associates, Inc., PRA Report 60-31, AF 19(604)-5616, Arlington 2, Virginia (AFCCDD-TN-60-26).

Maintenance personnel who had completed the AN/FST-2 course and served as AN-FST-2 technicians for a period of six months to two years served as subjects in the study. The study was conducted to provide materials and functional specifications for a self-instructional device for use in troubleshooting the Fine Grain Data Section of the AN/FST-2. The study began with the development of a troubleshooting performance test. The test was used to structure the requirements of the training program.

Training program materials were developed consisting of ten lessons, the first five dealing with a generalized technique that would be useful for fault location, per se, and the second five dealing more specifically with techniques for troubleshooting the AN/FST-2. Lesson tests were developed for self-tutoring. Job-aids such as functional diagrams were also developed. To test the effectiveness of the training materials matched groups of technicians were selected and assigned to "training" or "non-training" conditions. They were then tested on a series of problems in the AN/FST-2 with one fault in each problem.

The..."results indicate that the training and job-aid materials effected a highly reliable improvement in the performance of trained subjects on the evaluation test. Not only is the improvement highly reliable,...but the difference (in performance) is also rather large in terms of absolute gains."

Also presented are the functional specifications for the training program.

35. WHITMORE, P. G. Some problems in the analysis of troubleshooting behavior. HumRRO, Research Report, 2 October 1959.

Research was conducted in order to determine (1) effective troubleshooting procedures for the NIKE AJAX IFC system, (2) knowledge and skills which contribute to troubleshooting procedures, (3) training necessary for development of these

skills, and (4) generalized maintenance principles from a comparison between M33 and NIKE systems. Data was collected mainly from three previous studies on electronics maintenance and from a multiple-choice test given to maintenance people. In order to better discriminate between various forms of troubleshooting behavior, it was necessary to modify and add to the activity category system.

Books

36. GARNER, L. E. Pin-Point Transistor Troubles in Twelve Minutes. Chicago Educational Book Pub. Division, Coyne Electrical School, 1959.

37. MORSE, P. M. Queues, Inventories and Maintenance. The analysis of Operational Systems with Variable Demand and Supply. John Wiley and Sons, Inc., N. Y., 1958.

38. RIDER, J. F. Perpetual Trouble Shooter's Manual. New York, Radio Treatise Co.

39. TURNER, R. P. Basic Electronic Test Procedures; a Practical Handbook for Electronic Technicians. New York, Technical Division, Rinehart, 1959.

Collected Works

40. Human Engineering Bibliography 1956-1957. ONR Report ACR-32, October 1958.

41. Human Engineering Bibliography 1958-1959. ONR Report ACR-55, October 1960.

42. STANDLEE, L. S., POPHAM, W. J., and [illegible] N. A. A review of troubleshooting research. ONR Research Report No. 3, Project NR 151-167, Contract Nonr-908(07), December 1956.

43. STILES, H. J. and DEMAREE, R. G. Maintenance personnel and training research: A bibliography. HumRRO Staff Memorandum, March 1958.

44. BLACKSTON, M. W., & RABINE, N. Electronic troubleshooting trainer. Training Analysis and Development Division, 3380th Technical Training Group, Keesler Air Force Base, Miss., Final Project Report Keesler 56-1, Feb. 1956.

A description of a printed device for self-administration, designed to foster learning diagnosis of failure in electronic equipment. Developed by Van Valkenburgh, Nooger, & Neville, Inc. and called the "Trainer Tester." The electronics Troubleshooting trainer is recommended for developing the ability of a trainee to apply his academic knowledge systematically to practical situations. It provides training in troubleshooting logic and incorporates many desirable features. The trainer was specifically developed to implement the half-split technique in which an attempt is made at each step to eliminate about half of the possible defective areas. Suggested uses of troubleshooting trainers are (1) as homework assignments, and (2) during the time when the students are waiting their turn on the actual equipment.

45. BRYAN, G. L. Time required to troubleshoot a radio receiver as a function of type of information provided. USC Technical Report No. 21, Apr. 1957.

Electronics troubleshooting is viewed as a complex process of recognizing abnormal characteristics of malfunctioning equipment and organizing these abnormal indications into a pattern compatible with a hypothesis that a particular component is defective. Two experiments are reported in which the check readings provided to the troubleshooters are systematically varied. The purpose of this experimental work is to find what influence the variations have on making troubleshooting hard or easy. For both experiments, 42 experienced Navy technicians served as subjects. Synthetic problem materials were employed. The first experiment investigates the extent to which the difficulty level of a troubleshooting problem is dependent upon the size of deviations presented under problem conditions. Three levels of discrepancy are studied. The results indicate that reducing the size of the discrepancies makes the problem virtually insoluble. Increasing the size of the discrepancies in a problem beyond the point where they are clearly recognizable does not shorten the amount of time required for a solution. The second experiment determines the effect of manipulating the type of interpretive information available to the troubleshooter at each test point. Four different conditions of information are defined. In the minimum information condition the men are able to obtain readings which indicate to them that the circuit parameter is or is not within normal tolerance limits. In the maximum information condition they are provided with this information plus an indication of the magnitude of the deviation

of the obtained reading and its direction with respect to normal. Two intermediate points along an information value continuum are also represented. Results indicate that the additional interpretive information was of little benefit once the basic "normal-or-abnormal" decision was made.

46. CAMPBELL, J. T. and others. Prediction of success in the Radio Repairman Course. Personnel Research Branch, The Adjutant General's Office, Dept. of the Army, Washington, D. C., PRB Research Report 988, Dec. 1952.

The validities of each of the ten tests of the Army Classification Battery (ACB), the ten aptitude areas derived therefrom, and selected composites of the ACB tests were computed from data on two groups (N - 481 and 280) of enlisted men in the Radio Repairman Course using final grade as the criterion. Individual test validities, corrected for restriction in range, varied from .38 to .63. Validities for the aptitude areas ranged from .49 to .75. Cross-validity coefficients for composites of the most valid single tests did not exceed those for the most valid aptitude areas. Coefficients for years of civilian education and length of prior service ranged from .09 to .25.

47. CROWDER, N. A. A part-task trainer for troubleshooting. AFPTRC Development Report, AFPTRC-TN-57-71, June 1957.

It was desired to build an inexpensive part-task simulator for use in practicing troubleshooting, and in addition, to so organize supporting materials that a student could profit from practice with the part-task simulator without continuous expert supervision. Troubleshooting on the Sperry K- and MA-6 and MA-7 Bomb-Nav Systems was used as the development research vehicle. A simple device called the Malfunction Information Trainer (MIT) was developed which permits the student to obtain, for a specific malfunction, coded "test results" at any of 478 test points in the system under any of 28 different combinations of control settings and signal injection procedures, and to get an indication of the correctness of the diagnosis he reaches on the basis of these test results.

48. CROWDER, N. A. Recommendations for a Flight-line systems analyst course for the MA-6 and MA-7 Bombing and Navigational Systems. ASPRL Technical Memorandum, ASPRL-TM-56-7, March 1956.

Memorandum was prepared at the request of Strategic Air Command, on the idea that the primary duty of the flight line systems analyst is troubleshooting to the level of a replaceable system unit (black box), with associated duty of performing alignments and adjustments, if required. Major recommendations are: (1) course should include a thorough review of the data flow between

sub-units of the system; (2) course should include review of certain mathematical fundamentals; (3) course should teach explicitly only those electronic fundamentals required to understand the process of data transmission between units, and elementary applications of Ohm's law to circuit and continuity tracing; (4) course should specifically teach use of common test equipment and of mechanics maintenance manual; (5) course should provide student an opportunity to study functioning of the normal system in the same detail as required in checking malfunctioning system; (6) student should be required to work out theoretically the consequences of improper alignments and adjustments; (7) student should be taught troubleshooting as a systematic rational process with minimum of reliance on probability data; (8) student should receive intensive practice in all of the parts of a troubleshooting problem, as well as practice on complete problems; (9) major teaching technique should be supervised student practice in all phases of the course; (10) exams should be exhaustive of the material taught.

49. DOWELL, E. C. Evaluation of Trainer-Testers. Training Analysis and Development Division, 3380th Technical Training Group, Keesler Air Force Base, Miss., Final Report Keesler 54-28, June 1955.

This report attempts to evaluate the Trainer-Tester developed by Van Valkenburgh, Nooger, & Neville, Inc. in teaching troubleshooting techniques when used as a partial substitute for hard-to-obtain or critical equipment, and testing student performance. Most effective learning took place when students practiced solving troubleshooting problems on both the actual equipment and Trainer-Testers. Use of Trainer-Testers alone did not produce significant learning. Students manifested considerable interest in Trainer-Testers. Degree of adaptability of the concept to specific complex electronic equipment seems to be somewhat doubtful. In most instances it would be impracticable to keep such materials abreast of equipment modifications. The Trainer-Tester is not considered to be adaptable for use in testing; a satisfactory means of scoring was not discovered.

50. FOLLEY, J. D. Jr., SCHWEIKER, R. F., & FEROGLIA, W. E. Line maintenance of the A-3A Fire Control System: II. Job-task description. ASPRL Technical Memorandum, ASPRL-TM-55-3, Jan. 1955.

A study was made of the job and training requirements for line maintenance of the A-3A Fire Control System. Line maintenance job requirements were classified under checking, adjusting, troubleshooting, replacing, and repairing. A task analysis is included which was obtained by analyzing and describing job procedures. The procedure for troubleshooting is described.

51. FOLLEY, J. D., Jr., & MILLER, R. B. Summary Comparison of job requirements for line maintenance of three complex electronic systems. ASPRL Technical Memorandum, ASPRL-TM-55-17, Sept. 1955.

In previous study, an attempt was made to identify line maintenance job behaviors common to Q-24 and K-1 electronic systems. In this report a detailed comparison was made of analyses of behaviors, procedures, physical supports for discriminations, decision-making, and manipulations for the A-3A, Q-24, and K-1 systems. Results of this study suggest a number of instances in which transfer of skills and knowledges from one equipment to another might be realized; however, these were found to be relatively simple behaviors. It was discovered that the bulk of the maintenance procedures and information content are specific to each equipment. Major differences exist in the organization and sequences of behavior units into comparable procedures and tasks in each of the three equipments. The things which might be expected to transfer from one equipment to another are such skills as following of procedures as outlined in written job instructions and making of logical inferences in systematic troubleshooting. Common course of "fundamentals" training was not recommended.

52. FORD, J. S. A study of the utilization of sequentially obtained information in problem solving. Dissertation presented to University of California for Ph.D. degree, Jan. 1957.

Based upon a study of troubleshooting performance on the Generalized Electronics Troubleshooting (GETS) Trainer. Study was designed to determine relationships of two classes of variables--amount of training in particular problem-solving techniques, and psychometrically defined intellectual variables--to the "efficiency" with which individuals seek and utilize information available but not initially apparent or provided in the problem situation. Subjects were 90 high school junior and senior class males. Conclusions: (1) data suggest that speed of performance and logical efficiency of performance appear to be essentially independent; (2) increased practice in abstract troubleshooting significantly increased the logical efficiency with which subjects utilized information in similar problem-solving situations; (3) logically efficient utilization of information in abstract troubleshooting situations is significantly related to general level of mental ability; (4) in context of this study, general mental ability is not related to speed or pace of problem-solving performance; (5) specific mental abilities most strongly related to logically efficient performance were verbal comprehension and reasoning; (6) in solving problems of this type, results indicate evaluative reasoning is an important special ability underlying efficient problem-solving performance.

53. FRENCH, R. S., & MARTIN, L. B. A flight-line troubleshooting trainer for a complex electronic system; The MAC-2 Trainer. AFPTRC Development Report, AFPTRC-TN-57-106, July 1957.

This report describes the basic features of a trainer for the MA-7A Bomb-Navigational System which was developed as a possible solution to the need for individual troubleshooting practice. The present trainer has been designated the MAC-2 in recognition of its basic similarity to the MAC-1 Trainer, an initial experimental model for the K-3A system. The trainer was designed to supplement practical training and experience on the actual equipment by providing a ready opportunity for student mechanics and line maintenance personnel to learn and practice the basic operation of the MA-7A System, data-flow tracing and circuit analysis, the use of schematics, and the selection and use of appropriate test equipment.

54. FRENCH, R. S. Functional specifications for a bombing-navigational system troubleshooting trainer: The ASB-4 MAC-3 Trainer. ML Technical Memorandum ML-TM-57-9, July 1957.

This report outlines recommended functional specifications for a MAC-type trainer for the AN/ASB-4 Bombing-Navigational System; a secondary purpose of the report is to derive principles for the development of such specifications. This type of trainer is basically the same as the MAC-2 except that in many respects it should be simpler, more compact and dependable, and more versatile.

55. FRENCH, R. S., & MARTIN, L. B. The MAC-2 Troubleshooting Trainer for the MA-7A System. ML Technical Memorandum, ML-TM-57-4, May 1957.

Paper describes the general features and use of a synthetic troubleshooting trainer for the MA-7A Bomb-Navigational System. Since the trainer retains the basic approach to equipment simulation which characterized the K-3A/MAC-1 Trainer, it was designated the MAC-2. The need for further research and practical demonstration of techniques for using the MAC Trainer is described.

56. GOLDBECK, R. A., BERNSTEIN, B. B., HILLIX, W. A., & MARX, M. H. Application of the half-split technique to problem-solving tasks. J. exp. Psychol., 1957, 53, 330-338.

Report of two experiments on the use of the half-split method of locating trouble sources in malfunctioning equipment. Results indicated that where the system relationships were easily mastered, the half-split method was an aid to efficiency. However, either relatively high ability or instructional aid was needed to overcome load put on subject's capacities by the more complex systems. It was concluded that deductive ability is a prerequisite for application of the half-split technique and may play a preponderant role at each stage of the trouble-shooting task.

57. GUSTAFSON, H. W., HANSEN, O. K., SESSIONS, F. Q., & TAYLOR, C. W. The level of performance of K-System Flight-line troubleshooters. ML Technical Memorandum, ML-TM-57-24, Dec. 1957.

Report describes the troubleshooting performance of mechanics tested as part of a program in the development of improved methods of proficiency evaluation. Fifty-four K-System flight-line mechanics were tested on their ability to troubleshoot malfunctions inserted in a K-System bench mockup. The average mechanic displayed several deficiencies in troubleshooting ability. One common error was the failure to identify obvious signs of malfunction before starting to make detailed trouble-shooting checks. Another tendency was to make hasty guesses instead of performing simple checks. Despite shortcomings in procedures, examinees were able to solve most of the malfunction problems; most could handle their jobs even though they worked extremely inefficiently. Mechanics agreed that the test was not too hard, that it required them to apply almost everything they knew about the K-System. The real problem is one of training, but it is very difficult to conduct training and to perform maintenance at the same time.

58. GUSTAFSON, H. W., TAYLOR, C. W., & HANSEN, O. K. The MAC-2 Trainer as a substitute for a mockup in the performance testing of K-System troubleshooters. ML Technical Memorandum, ML-TM-57-19, Oct. 1957.

Study involved a comparison of troubleshooting performance on a K-System mockup with performance on the MAC-2 Trainer. Method consisted in putting mechanics to work on malfunctions in the mockup and trainer, allowing free rein as to troubleshooting procedures, and observing step-by-step performances. Basic question was whether a set of malfunctions could be found that would elicit essentially the same kinds of behavior on the trainer as on the mockup. Because of its design, the MAC-2 Trainer is excessively difficult to substitute for a K-System mockup; since trainer is a binary or "go-no go" system, restrictions are automatically placed on choice of malfunction problems. As a rule, trainer malfunctions are easier than those encountered on the job. Also, trainer malfunctions do not behave in exactly the same way that they do on a mockup. It is not easy to teach examinees how to operate the trainer. Perhaps the trainer's biggest advantage is that it reduces average time required to test each mechanic. However, saving in testing time is more than offset by length of training period that appears to be necessary.

59. HOEHN, A. J., & WARDELL, W. C. Development of an experimental trouble-shooting guide for the F-86D integrated electronic fuel control system. ML Technical Memorandum, ML-TM-57-25, Dec. 1957.

Description of development of F-86D electronic fuel control system troubleshooting guide. Work was undertaken to develop

and try out a method, not as a matter of direct operational support. Major use for the guide was to demonstrate potential effectiveness of carefully designed procedural troubleshooting instructions for (a) improving job performance of lower level technicians, thus decreasing work load of higher level technicians; (b) increasing efficiency of procedures used in troubleshooting; and (c) reducing amount of time equipment is out of commission. Sections of the report deal with procedures, preparation and description of guide, potential uses of guides, and requirements for further research and development. Several illustrations.

60. HOEHN, A. J., AUKES, L. E., & SALTZ, E. Evaluation of an experimental guide for troubleshooting the F-86D & L electronic fuel control system. ML Technical Memorandum, ML-TM-57-33, Dec. 1957.

Results of evaluation of experimental guide for troubleshooting the F-86D and L integrated fuel control (IEC) system. Comparison in this study is not comparison of performance with a troubleshooting guide, and without any form of printed job aid, but rather a comparison of the relative performance effects of the troubleshooting guide and the manufacturer's handbook. Sixteen IEC personnel at Ethan Allen Air Force Base with various combinations of training and experience were tested. Results seem to warrant the following conclusions: (1) guide would prove helpful to IEC men who have not acquired a high level of familiarity with the IEC system; (2) properly used, the guide can increase effectiveness of utilization of less qualified IEC technicians and decrease dependence on IEC specialists or technical representatives; (3) results are sufficiently favorable to warrant development and tryout of similar materials on other equipments; (4) guides should be developed from the outset in conjunction with development of original training program.

61. HOEHN, A. J. Troubleshooting guide--F-86D integrated electronic fuel control (trial form). ML(1956-1957).

Pocket-sized booklet designed for use by relatively inexperienced mechanics responsible for line maintenance of the electronic fuel control system on the J-47-GE-17 engine. It attempts to simplify troubleshooting process by presenting detailed procedures appropriate for checking out the fuel control system and for identifying a malfunctioning unit. Use of tabs provides quick reference to section desired. The guide was developed for ADC and was tested with good results.

62. KOLSTOE, R. H., and others. Ordnance IFC electronics maintenance personnel. Analysis of activities with implications for training. Part I. M-33. HumRRO Technical Report 31, Sept. 1956.

Study was designed to provide information concerning job in the field of third and fourth-echelon electronics maintenance

personnel in ordnance detachments. Report is specifically concerned with four main problems: nature, extent, and frequency of tasks performed by electronics maintenance personnel; current level of proficiency of these men; nature and extent of on-the-job training programs; and the relationship between various job requirements and specific aspects of the school training program. HumRRO research teams gathered data from 381 officers and enlisted men in 30 ordnance detachments located in the U. S., Alaska, Far East, and Europe. Some findings included: (1) tasks performed by graduates of the advanced course and by graduates of basic course differed not in type but in level of proficiency with which they were performed; (2) present basic electronics course is required to produce two different types of end products; (3) there was general agreement among field personnel contacted that ideal on-the-job training method for new graduates of either course was to have them work with experienced repairmen. Recommendations were made concerning training programs and job activities.

63. KOLSTOE, R. H., CZEH, R. X. & ROZRAN, G. B. Ordnance IFC electronics maintenance personnel. Analysis of field activities with implications for training. Part II--T-38. HumRRO, Technical Report 37, March 1957.

Data describing the job done in the field by third and fourth-echelon electronics maintenance personnel were obtained in 22 ordnance detachments (IFC T-38) in the U. S. and overseas. Field maintenance activities and procedures, test equipment and manual usage, job proficiency, on-the-job training experiences, and the "value in maintenance" of school training subjects were analyzed for graduates of both basic and advanced electronics courses. Recommendations are made for emphasis on specific areas of training and for reorientation of training programs.

64. KRIEGH, B. Optiral sequences for troubleshooting. ML Technical Memorandum, ML-TM-57-30, Dec. 1957.

A mathematical formulation of the problem of locating a defective element which is part of a complex system of components is given. In several special cases an analytical procedure is then given for the determination of the most effective test checking sequence. Results obtained are: (1) for a set of elements in parallel, the t/p procedure gives the least average time and if inference is used, a procedure is given for determining the element to be omitted from checking sequence; (2) for a set of elements in series, when time factors are equal and the probability factors equal, the half-split method gives the least average time; (3) for a set of elements in series when the time factors are unequal, a modified half-split probability method gives least average time; (4) a procedure suitable for programming on a digital computer is given for determination of the best test checking sequence for a single chain of elements connected in series.

65. **KRULEE, G. K.** Human factors in electronics reliability. Tufts College, Medford, Mass., July 1954.

This report reviews studies of human factors in the reliability of electronic equipments and provides an interpretive summary of the major findings and implications. Introductory sections of the report contain a discussion of the diagnostic elements of maintenance activities and of the information-processing aspects of diagnostic tasks. It is suggested that efficient diagnosis is impossible unless the necessary information is readily available and unless this information can be interpreted with reference to a prior knowledge of the normal or desired state of the system and of its components. The possible application of present day theories of information processing to the simplification of preventive maintenance and fault location is discussed. Implications for equipment design are described, particularly with reference to the inclusion of built-in test facilities so that fault location and the routine monitoring of equipment performance can be more readily accomplished.

66. **MILLER, R. B., FOLLEY, J. D., Jr., & SMITH, P. R.** Systematic troubleshooting and the half-split technique. HRRC Technical Report 53-21, July 1953.

A description of procedures based upon rational and logical considerations was presented for troubleshooting of electronic equipment. Two alternative methods were specified and have been termed "troubleshooting from probability data" and "troubleshooting by logical elimination of malfunction sources."

67. **PSYCHOLOGICAL SERVICES INC.** Basic troubleshooting: (1) Instructor's guide; and (2) student's workbook. Working documents prepared under Contract AF 18(600)-1206 with Psychological Services, Inc., Los Angeles, California, 1955.

The student workbook is to be used in training on the Generalized Electronic Troubleshooting (GETS) Trainer, which outlines rules and methods for troubleshooting electronic equipment in general. Included are chapters dealing with kinds of data flow chains, troubleshooting linear chains, troubleshooting diverging chains, troubleshooting converging chains, and troubleshooting complex systems. The instructor's guide contains the actual course content reproduced exactly as it appears in the pages of the student workbook, and instructor's notes designed to aid the instructor in teaching course content, arranged on opposite pages.

68. **RAY, W. S.** Verbal compared with manipulative solution of an apparatus problem. Amer. J. Psychol., 1957, 70, 289-290.

This experiment asks whether subjects may solve problems in a different way if they are forced to talk, and so presumably to think, about them before doing anything else about them. It is related to an experiment by Saltz, Moore, and Hoehn, which suggests that Ss do a better job of finding sources of trouble in electrical equipment if they "preplan" (i.e., make a plan for) their work. A group of 64 basic airmen solved an equipment problem which resembles a search for a malfunction. Another group solved the problem but only after its members told experimenter what they would do before they actually touched the apparatus. The Ss of the latter group made fewer repetitive errors and required fewer trials than did the purely manipulative solvers.

69. **SHERRIL, P. N.** What to emphasize in maintenance manuals. Electronics, 1956, 29, 150-152.

Results of a survey of several hundred people who maintain equipment, made by Hewlett-Packard Co., Palo Alto, Calif. In preparing commercial manuals, assumption is usually made that technician or reader has a knowledge of electronics, has been trained to some extent in his art, and understands most language on a technical level, as opposed to at least some military agencies which assume the reader has no previous knowledge of the equipment and that his education may not extend beyond the grammar school level. Maintenance information is presented in order of importance to technicians surveyed:

1. Schematic diagram--if equipment is complex, furnish both fold-out integrated type and single-page sectionalized type. Include component values, pin voltages, and tube functions on schematic.
2. Circuit description--the more complete the better.
3. Waveforms--peak voltages should be given.
4. Voltage and resistance diagram--too useful to leave out.
5. Tube replacement chart--show adjustments to be made when tubes are replaced. Describe critical tubes.
6. Circuit block diagram--good in circuit descriptions but well organized schematic is superior for servicing.
7. Troubleshooting chart--it should check and adjust unit completely, rather than act as a catalog of possible failures.
8. Internal views--necessary only when chassis cannot be silk screened clearly.
9. Tube location diagram--mark chassis instead.
10. Resistor-board details--mark boards instead.

70. **SIEGEL, A. I** The troubleshooting ability of graduates and nongraduates of a Naval technical school. Psychological Reports, 1956, 2, 263-266.

Comparison was made between troubleshooting ability of naval aviation electricians who had graduated from Navy schools for aviation electricians, and troubleshooting ability of aviation electricians who had not graduated from these schools. AE Troubleshooting Examination was administered to 113 graduates from A school for aviation electricians and to 49 nongraduates. Generally in the three lower rates, graduates were found to be superior; however, in the case of aviation electricians first class, graduates were not superior. Attendance at the schools seems to have acted most to raise functional level of graduates to diagnose and perform electrical checks, as well as their knowledge of principles. School attendance seems to have affected least the ability of its graduates to perform basic skills necessary for electrical maintenance.

71. **STOLUROW, L. M., BERGUM, B., HODGSON, T., & SILVA, J.** The efficient course of action in troubleshooting as a joint function of probability and cost. Educ. psychol. Measmt., 1955, 15, 462-477. (Also published as AFPTRC Research Report, AFPTRC-TN-56-71, June 1956.)

The present study was designed to: (1) determine the critical characteristics for decision-making when a task is to locate defective components in a complex equipment system; and (2) derive for this type of decision-making a model capable of providing both general and specific guidance for training and for organizing the information content of job aids. The method used had two components. The larger effort consisted of analyzing maintenance records obtained from 46 operational four-engine aircraft--a 28- cylinder reciprocating engine (R-3360). The smaller effort consisted of the administration of two detailed questionnaires to 10 experienced instructors at a resident training school. In this type of problem-solving situation, a useful model for guiding decisions is one based upon two critical assumptions for each set of relationships of symptoms and causes: (1) that the relationships are probabilistic with values not equal to each other, and (2) that the work-time values associated with checking possible defects are different from one another and vary over a considerable range. The parsimonious solution derived from the model can be generally applied in troubleshooting situations of this type. It consists of using the ratio of cost (e.g., work time) to probability for each of the possible defects, i. e., c/p. These ratios ordered from lowest to highest can be used to indicate the most efficient action sequence to be followed in locating a particular defect. Mechanics using them to identify the source of malfunction would, on the average, locate it in the least average time.

72. TUCKER, J. A., Jr. Experimental development and evaluation of a K-System Troubleshooting Trainer-Tester. AFPTRC Development Report, AFPTRC-TN-57-34, Mar. 1957.

Study is needed to determine empirically the training value resulting from the use of symbolic trainers that represent complex electronic equipment. The experimental device described in this report is a printed troubleshooting trainer. It permits practice of a logical troubleshooting procedure for trouble-shooting to the "black box" level a complex bombing-navigation system, the Sperry K-System. The study also includes an evaluation of the K-System troubleshooting Trainer-Tester package. It is recommended that in-service Air Force experimental development of symbolic trainers of both paper-and-pencil and physical equipment types be continued.

73. WARFIELD, J. N. Optimum diagnostic sequences for complex systems with one faulty element. Control Systems Laboratory, University of Illinois, Report M-67, Feb. 1957.

One approach to the problem of maintenance of complex systems has been the design of self-repairing systems. The diagnostic job is an extremely difficult part of this problem, which extends backward to design; hence it is seen that the core of the problem is to develop a general theory of diagnosis for the guidance of the designer. In this paper a method for determining an optimum diagnostic sequence to locate a single fault in a complex system is presented and illustrated with a numerical example.

74. WARREN, N. D., SCHUSTER, D. H., FRENCH, R. S. The trouble locator--a troubleshooting aid for a complex electronic system. ML Technical Memorandum, ML-TM-57-22, Nov. 1957.

This study was concerned with the development of an aid to assist the line mechanic in his job. The development of a troubleshooting aid for a complex electronic system may result in shorter training periods for mechanics, the use of less experienced personnel without sacrificing operational maintenance, and simultaneously permit a period of time on the job during the mechanic's initial enlistment. This pocket-sized booklet, called the K-System Trouble Locator, consists of systematic checks designed first to localize the trouble to an area of the K-System, to pin it down to a particular loop, and finally, to isloate the source of trouble to a specific component. This study demonstrated that troubleshooting devices are possible and could be applied to other complex systems to help alleviate the maintenance personnel shortage.

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